**HYDRAULICS I**

1. **Introduction**

Objectives of this section after studying this chapter the student should understand and:-

 Define Hydraulics Differentiate Fluid mechanics and Hydraulics

 Application of hydraulics

 Importance of studding Hydraulics

**1.1What is hydraulics?** Hydraulics is derived from a Greek Word “Hydraulikos" which means water. It is the study of water and some engineering fluids, which a hydraulic/civil engineer is called upon to store, convey or pump. Engineering fluid includes wastewater in waste disposal and oils in hydraulic control gear.

**Activity1.1: What is the difference between Hydraulics and Fluid mechanics?**

Hydraulics is often confused with the allied science of fluid mechanics because a considerable overlap occurs between the two studies. However, fluid mechanics deals with gases, as well as the common liquids, and to most hydraulic/civil engineers a study of gas behavior is irrelevant to their professional needs. The basic aim of hydraulics is to understand and control the occurrence, movement and use of water for the benefit of society whether it is in lakes, rivers, pipes, drains, percolating through soils or pounding the coastline as destructive waves. Therefore, the fundamentals in hydraulic engineering systems involve the application of engineering principles and methods to the planning, control, transportation, conservation, and utilization of water. Fluid mechanics is a branch of mechanics and studies about fluid (liquid + Gasses) while Hydraulics is a branch of fluid mechanics which studies about engineering liquids i.e. Most of the time Hydraulics is concerned with water.

Generally, fluid mechanics is about fluid while Hydraulics is concerned with engineering liquids. The basic aim to study Hydraulics is to control and understand:-

 Occurrence

 Movement

 Use of water for the benefit of society.

**Activity 1.2: Why do we study Hydraulics?**

We study hydraulics:-

To supply the society with adequate water

To dispose waste and excess water

To protect the society from uncontrolled water.

**Activity1.3: Where we apply hydraulics?** Hydraulics is applied for different purposes such as:  Design of wide range of Hydraulic structure (dams, canals weirs etc.) And machinery (pumps, turbine etc.)

 Where design of the complex network of pumping and pipe lines there for transporting liquids.

 Power generation

 Flood protection

 Surface and ground water studies

 Flow metering like orifice meter

 Pressure measurement

### Chapter – 2

### 2. FLUID PROPERTIES

* 1. **General Description**

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atter can be distinguished by the physical form of its existence (**phases**) as solid, liquid and gases, for example water appears in liquid, solid (Snow and ice), or gaseous (moisture or water vapor) form depending on the extent of hydrogen bonding. Liquid and gaseous phases are usually combined and given a common name of fluid.

**Exercise**: Distinguish solid, liquid and gas.

**Definitions**

### Fluids: *Fluids are substances, which deform continuously under the application of a shear force, no matter how small the force might be. They are characterized by their ability to flow.*

(Shear force = force component tangent to a surface. This force divided by the area = average shear stress).

**Properties**: *intensive, extensive, physical and chemical.*

Every fluid has certain characteristics by which its physical condition may be described. These properties can be divided in to two broad categories: Extensive properties, which depend on the size of a sample of matter; and intensive properties, which are independent of the sample size. Of the two intensive properties are the more useful because a fluid will exhibit the same intensive property regardless of how much of it we examine. Examples of extensive property are mass and volume as the amount of a substance increases; its mass and volume also increase. Intensive properties include density, pressure and temperature.

In speaking of the properties of fluids, we also distinguish between physical and chemical properties. A physical property can be specified without reference to any other fluid. Density, mass volume, color etc are all examples of physical properties. A chemical property on the other hand states some interaction between chemical substances.

The way fluid (water) behaves under various conditions encountered in practice depends primarily on its fundamental and physical properties, which are briefed as follows.

* 1. **Physical Properties**

An understanding of fluid behavior and application of its basic laws through experimentation advances the subject of hydraulics. Fluid properties play principal roles both in open channel and pipe flow.

The principal physical properties of fluids are described as follows.

**2.2.1 Density**

There are three forms of density

a. Mass density or density, denoted by ρ (Greek, rho)

It is defined as the mass per unit volume.

Or density = 

* + SI unit Kg/ m3
  + Dimensionally ML-3
  + For an incompressible fluid, ‘ρ’ is constant
  + For water, ρ is 1000 kg/ m3 at 40 c and standard pressure (760 –mm Hg) (There is a slight decrease in density with increasing temperature, but for normal practical purposes the value is constant)
  + Generally, the density of liquids is only slightly dependent on either temperature or pressure and the variation can be ignored but for gases, it significantly varies with both temperature and pressure.

b. Specific weight / unit weight / unit gravity force /, designated by γ (Gk, gamma)

It is defined as the weight per unit volume.

 W = weight = mass x gravitational acceleration (g)

* + SI unit N/m3 (usually KN/ m3)
  + Dimensionally (ML –2 T-2)
  + At 40c ‘γ’ for water is 9.806 / 9.81 KN /m3/
  + It changes with location on the earth’s surface depending upon g.

c. Specific gravity (S) or relative density (rl. dn.)

It is defined as the ratio of mass of a body to mass of an equal volume of a substance taken as a standard (for liquids water at 40 c)



* It is a pure no (dimensionless parameter)

**Typical values of specific gravities*:***

* Relative density of water is 1.00 (R.D of water = 1.00, standard for measuring relative density of other liquids).
* R.D of mercury = 13.6, commonly used secondary fluid in manometers for pressure measurement.
* Oils usually have a relative density less than one and they float on water.
* If relative density of a given oil is 0.8 its density is 0.8 (1000 kg / m3) = 800 kg/ m3

**Note:**

It is clear that density, specific weight, and specific gravity are all interrelated and from knowledge of any one of the three the others can be calculated.

**2.2.2 Specific Volume (Vs)**

It is the volume occupied by a unit mass of fluid or simply the reciprocal of density.



* Commonly applied to gases

**Example 1**

A mass of liquid weights 600N when exposed to standard earth’s gravity g = 9.81m/sec2

a. What is its mass?

b. What will be its weight in a planet with acceleration due to gravity is 4m/sec2.

c. What will be its density if the volume of the liquid is equal to 0.06116m3?

**Solution**

Let w = weight of liquid

m = mass of liquid

a) W = mg



b) If g = 4m/sec2

Therefore weight = mg

= 61.16\*4

= 244.6N



**Example 2**

10 liters of a liquid of specific gravity 1.3 is mixed with 8 liters of a liquid of specific gravity 0.8. If the bulk of the liquid shrinks by 1% on mixing, calculate the specific gravity, mass density, the volume and weight of the mixture.

Solution

Let V1 = 10 liters = 0.01m3, Sp. gr 1 = 1.3

V2 = 8 liters = 0.008m3, Sp. gr 2 = 0.8

Total volume = V1 + V2

= 0.01 + 0.008

= 0.018m3 (ans)

After shrink by 1%, volume of mixture = 0.018 \* 0.99

= 0.01782m3



ρliquid 1= Sp. gr 1 \* ρwater ρliquid 2 = Sp. gr 2 \* ρwater

= 1.3 \* 1000kg/m3 = 0.8 \* 1000

= 1300kg/m3  = 800kg/m3

Therefore mass m1 = ρliquid 1 \* Vol. 1 mass m2 = ρliquid 2 \* Vol. 2

= 1300\*0.01 = 800 \* 0.008

= 13kg m2 = 6.4 kg

Total mass = m1 + m2 = 13 + 6.4 = 19.4 kg

* Density of mixture =  (ans)
* Specific gravity =  (ans)
* Weight of mixture = mass \* g

= 19.4 \* 9.81

**= 190.314N** (ans)

**Bulk modulus of elasticity or Compressibility, K (kappa**)

* For most practical purposes liquids may be regarded as incompressible. All fluids may be compressed by the application of external force and when the external force is removed the compressed volumes of fluids expand to their original volumes. Thus fluids also possess elastic characteristics like elastic solids. Compressibility of a fluid quantitatively expressed as inverse of the bulk modulus of elasticity k of the fluid.

If the pressure of a volume of fluid is increased by dp, it will cause a volume decrease dv, then the bulk modulus of elasticity is defined as

Bulk modulus (K) = (stress=change in pressure) / (volumetric strain)

K = -  v = original fluid volume

The negative sign indicates a decrease in volume with the increase in pressure.

ρ = m/v

Mass of a certain volume is constant, differentiatingρ.





Substituting: 

* The concept of the bulk modulus is mainly applied to liquids, since for gases the compressibility is so great that the value of K is not a constant
* For water, k is approximately 2150 N/ mm2 at normal temperatures and pressures.
* For steel k = 215000 N/ mm2 (i.e. water is 100 times more compressible than steel)

**Absolute / (Dynamic) Viscosity (μ = mu)**

The resistance to flow because of internal friction is called viscous resistance and the property, which enables the fluid to offer resistance to relative motion between adjacent layers, is called the viscosity of liquid. It is a measure of resistance to tangential or shear stress and arises from the interaction and cohesion of fluid molecules.

The liquid molecules are closely spaced, with strong cohesive forces between molecules, and the resistance to relative motion between adjacent layers of fluid is related to these intermolecular forces. As the temperature increases, the cohesive forces are reduced with a corresponding reduction in resistance to motion, since viscosity is an index of this resistance, it follows that the viscosity is reduced by an increase in temperature.

A gas, on the other hand, has very small cohesive forces. Most of its resistance to shear stress is the result of molecular interaction. As the temperature of the gas increases, the random molecular activity increases hence viscosity increases with temperature.

The effect of temperature on viscosity is approximated by

**For gases**

 C and S empirical constant

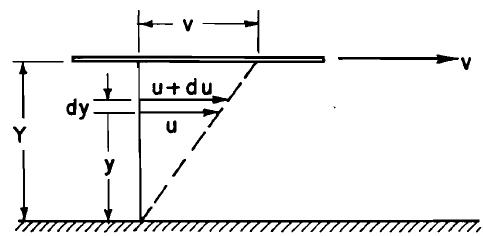
(Sutherland equation)

for liquids

 D and B constant, T=absolute temperature

(Andrade’s equation)

Consider two plates sufficiently large placed a small distance Y apart, the space b/n them being filled with fluid. The lower plate is assumed to be at rest, while the upper one is moved parallel to it with a velocity V by the application of a force F, corresponding to area A, of the moving plate in contact with the fluid.



Moving plate

Stationary plate

Fig1.1Fluid motion between two parallel plates.

It may be seen from similar triangles in figure 1.1 that the ratiocan be replaced by the velocity gradient, which is the rate of angular deformation of the fluid. If a constant of proportionality μ be introduced, the shear stress τ equal to b/n any two thin sheets of fluid may be expressed as



1

Where A = area of upper plate

* τ (tau) = shear stress

Equation 1 is called Newton’s equation of viscosity, and in the transposed form it serves to define the proportionality constant.

 2

This is called the coefficient of viscosity, or the dynamic viscosity or simply viscosity of the fluid. Thus the dynamic viscosity μ, may be defined as the shear stress required to produce unit rate of angular deformation.

* Heavy oils have greater viscosity than water and water is more viscous than air.
* All real fluids posses viscosity, though to varying degrees.
* There can be no shear stress in a fluid, which is at rest
* The SI unit of μ is N.s /m2or Pa.s (kg/ m.s),
* Or in cgs system  termed as poise
* One poise = 0.1 Ns/m2 = 0.1 kg m-1 s-1 = 0.1 Pa.s
* Dimensionally = (ML-1 T-1) (FL-2 T)

In many problems concerning fluid motion the viscosity appears in the form of μ/ρ and it is convenient to employ a single term ν (nu), known as kinematic viscosity, and so called because the units m2/s (L2T-1) is independent of force.

Kinematic viscosity = 

* SI unit of ν is m2/s in cgs system cm2/s called stoke.
* For water, ν = 1.14 mm2/s at 150c
* For heavy air ν may be as high as 900mm2/s.
* Viscosities (absolute of dynamic) of liquids decrease with increasing temperature but are not affected appreciably by pressure changes.

Determination of viscosity

The following methods may be employed to determine the viscosity of liquid

1. Capillary Tube (Reading exercise)
2. Sphere Resistance (attend the experimental demonstration )
3. Rotating cylinder

**Viscometer**

It is an instrument to measure viscosity. It measures some quantity which is a function of viscosity. The quantity measured is usually the time taken to pass a certain volume of liquid through an orifice fitted in the bottom of viscometer. The temperature of liquid while it is being passed through the orifice should be maintained constant.

Example

If the velocity distribution over a plate is given by  in which u is the velocity in m/sec at a distance y meters above the plate, determine shear stress in N/m2 at y=0 and y=0.15m. Take μ = 8.63poise

**Solution**





Hence 



### Newtonian and Non - Newtonian fluids

Fluids are classified as Newtonian or non - Newtonian.

A fluid, which obeys Newton’s law of viscosity, is known as a Newtonian fluid and they will have a certain constant viscosity. For these fluids the plotting of shear stress against velocity gradient is a straight line passing through the origin. The slope of the line gives viscosity.

Examples of Newtonian fluid are water, air, gasoline and light oils. (Under normal condition)

In a non- Newtonian fluid there is a non -linear relation between the magnitude of applied shear stress and the rate of angular deformation.

Ex: non - Newtonian fluid: human blood, butter, printers ink etc….

* Gases and most common liquids tend to be Newtonian.
* Newtonian and Non - Newtonian fluids are real fluid.

### Ideal fluid

For purposes of analysis, the assumption is frequently made that a fluid is non -viscous (frictionless) and incompressible (inelastic). Such an imaginary fluid is called ideal or perfect fluid.

### Ideal solid

No deformation will occur under any loading condition, and the plotting coincides with the y -axis. Real solids have some deformation; within the proportional limit (Hooke’s law) the plotting is straight line, which is almost vertical.

### Ideal plastic

Sustain a certain amount of shearing stress without deformation and thereafter it would deform in proportion to the shearing stress. If not proportion they are called thyxotropic fluid.



Newtonian

Non-Newtonian

Ideal plastic

Ideal solid

Ideal fluid

Shear stress, τ

Slope=μ

τ

dv/dy

Velocity gradient (rate of deformation), dv/dy

Fig1.2. Plot of τ versus dv/dy

* 1. **Surface tension denoted by σ (Gk. Sigma)**

Considering the behavior of molecules at the interior & along the surface of a fluid mass can give us a clear understanding of surface phenomena. Take molecules in the interior of a fluid mass. They are under attractive forces in all directions and the vector sum of these forces is zero. However, at the surface between liquid and air or two immiscible liquids the upward and downward attraction are unbalanced (acted on by a net in ward cohesive force that is perpendicular to the surface) which causes the surface to behave as if it were a ‘skin’ or elastic membrane stretched over the fluid mass giving rise to the phenomenon of surface tension. Actually such a skin doesn’t present, but this conceptual analogy allows as to explain several commonly observed phenomenon. This is demonstrated schematically in the following figure for water with a free surface.

Air

Water

Fig1.3 Surface tension due to molecular attraction.

Generally surface tension is a force, which exists on the surface of a liquid when it is in contact with another fluid or a solid boundary. Its magnitude depends up on nature of the liquid, and the surrounding matter which may be a solid, liquid or a gas, Kinetic energy and hence the temperature of liquid molecules (or the relative magnitude of cohesive and adhesive forces.)

Surface tension effect enables:

* An isolated drop of liquid to take nearly a spherical shape.
* A drop of water to be held in suspension at a tap.
* Birds to drink water from ponds.
* A vessel to be filled slightly above the brim.
* Dust particles and needle to float on the surface of liquids.
* Capillary rise and depression in thin-bored tubes.

**2.4 Capillarity or meniscus effect**

When a tube of small diameter called capillary tube is inserted in to a container of liquid, the level will rise or fall within the tube depending up on the relative magnitudes of the cohesion of the liquid and the adhesion of the liquid to the wall of the containing vessel. Liquids rise in tubes they wet (adhesion > cohesion) and fall in tubes they do not wet (cohesion > adhesion) see the following figure.

The phenomenon of rise and fall of liquid in a capillary tube is known as capillarity. Capillarity is important in capillary tubes, monometer or open pores in the soil. (Tubes ≤ 10 mm diameter).

h

A

B

C

D

Fig1.4. A) Rise of column of liquid for wetting liquid b) depression of column for non-wetting liquid.

The magnitude of the capillary rise (or depression), h, is determined by the balance of adhesive force between the liquid and solid surface and the weight of the liquid column above (or below) the liquid free surface.

For Fig a The gravitational force on the column of liquid elevated must be supported by surface tension acting around the periphery of the tube.

∴ 

Component of forces = weight of volume

Due to surface tension (ABCD) → neglecting pressure forces.

⇒ h =  h=

It is to be noted that for 0 ⊆ θ⊆ 900 h is positive (concave meniscus and capillary rise) and that for 90 ⊆ θ⊆ 1800 h is negative (convex meniscus and capillary depression).

* For pure water and clean glass θ = 00
*  for water = 0.0735 N/m

In case of liquid drop or inside a jet, the action of surface tension is to increase the internal pressure

For a liquid droplet

Considering force balance on a hemispherical drop, it is possible to equate the change in pressure (which is trying to blow apart the two hemispheres) and the surface tension  (which is trying to pull them together).See the following figure

Therefore, Δp πd2/4 = **πd

Δp=4**/d

σ

P

Fig1.5. Pressure in a sphere due to surface tension

**Exercise:**

Similarly show that Δp=2σ/d and 8σ/d for jet of water and soap bubble respectively.

**1.2.7 Vapor pressure**

The vapor pressure of a liquid is the (generally small) pressure at which the liquid vaporizes or boils as it changes from the liquid to the gaseous or vapor state. The vapor pressure is strongly dependent on temperature. Water boils at atmospheric pressure when the temperature is 1000c and at higher elevations the atmospheric pressure is less; hence, water evaporates at temperatures lower than 1000C. This property usually has no effect on a fluid flow; however, if a flowing liquid experiences a pressure at any point, which lowers the pressure locally to the vapor pressure for that temperature, then this vaporization, will take place. In problems involving siphoning, the result of pressure reduction to the vapor point will be to break the siphon and interrupt the flow. In other cases the flow will continue, altered in form, as the phenomenon of capitation occurs. Capitation is the rapid formation and collapse of small vapor bubbles, which are not only disruptive, but are also frequently destructive as well. This subject will be treated more fully in other courses.